SMITH & WRIGHT

A Study of Carbon Resistance

Electrical Engineering

B. S.

1912

# A STUDY OF CARBON RESISTANCE

BY

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AND
JOHN EDWARD WRIGHT

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THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

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COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1912

# UNIVERSITY OF ILLINOIS

May 31, 1912

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

CLOYD CLAYTON SMITH AND JOHN EDWARD WRIGHT

ENTITLED A STUDY OF CARBON RESISTANCE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

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# TABLE OF CONTENTS.

## INTRODUCTION.

It has been known, perhaps since the discovery of electricity that, whenever a circuit is closed through a contact, there will be introduced a resistance due to this imperfect connection. By increasing the pressure bearing on these connecting parts, it is possible to lower this contact resistance. This effect is most noticeable in hard carbon, the structure of which prevents a perfectly smooth surface being made. This phenomenon enters into many of the commercial products of today. In motors we have carbon brushes resting on rotating commutators, in switches flat carbon surfaces are brought together, and in telephones, the possibility of transmission of speech is due to the fact that granulated carbon changes its resistance when compressed by the pressure caused by vibrating sound waves. While it is more or less harmful the first two cases it is very necessary in the last case.

It then seems that if some definite laws exist in the relation of resistance to pressure, it might be possible to use this phenomenon of contact resistance to advantage in other ways. The aim of this investigation is to obtain data from which such laws may be formulated, providing they exist, or to prove their non-existence. It is also our purpose to determine the possibility of using this phenomenon to indicate the pressure in high speed gas engine cylinders.

## DESCRIPTION OF APPARATUS.

The apparatus used to apply pressure to the carbon is shown on pages 6 ,7 and 8 . Supported, above a wrought iron base, on three brass rods, is a triangular brass plate one eighth of an inch thick. In a hole in the center of this plate rests a hollow brass post. A brace runs from one vertex of the triangular piece across the top of this post to the middle of the opposite side. The post is threaded on the inside and into it is screwed a brass plunger on which are nuts to lock it firmly at any desired position. Directly under the plunger is a stirrup which holds the material being tested. The stirrup is hung ,by two knife edges, from the end of the lever. The lever is supported by two knife edges resting on posts about two inches on either side of it. On the other end of the lever is suspended,on one knife edge, the scale pan in which the weights are placed. A counter-balance was hung from the stirrup to balance the lever. By screwing the plunger up and down, the lever was held horizontal for the different sized piles of carbon. This eliminated errors due to friction or changing position of the lever. This lever was made of one and one half inch by three eighth inch wrought iron.

To measure the deformation of the pile, a wire wound deflectometer was used. This is shown on page 8 . With it deformations could be read to one thousandth of an inch.

Electrical circuit was completed by connecting to the plunger at the top of the pile and a brass plate at the bottom. This plate was well insulated from the stirrup in which it rested, so there was no danger of short circuit through the frame.

In order to keep the disce in alignment and to keep the temperature constant, a fibre tube was placed around the pile of discs. In the side of this tube a hole was cut to let the thermometer come close to the carbon. The whole was then wrapped with several thicknesses of tape. The thermometer read to 200° Centigrade. A Weston voltmeter and ammeter were used to measure the current and the potential drop across the discs. These instruments were carefully calibrated so as to make the results as accurate as possible.

The apparatus used for the engine indicator is shown on page . The recording cylinder of the indicator was removed and in its place a heavy brass post was set. An arm, made by bending a broad brass plate, held a hard rubber cylinder one and one thirty second inches inside diameter. The indicator piston rod was extended to connect with a plunger in the bottom of the cylinder. The carbon was placed in the cylinder on this plunger and another plunger fastened in the top of the cylinder by a brass screw cap. These two plungers formed contacts by which the carbon could be connected into the circuit of a battery and an oscillograph. The oscillograph used was one made by the General Electric Company.

## DESCRIPTION OF MATERIAL.

Three forms of carbon were used in the tests. The one form investigated most thoroughly was carbon in the shape of discs one inch in diameter and one sixteenth of an inch thick. These were supposed to be perfectly flat but in reality were not on account of a slight warping. Some of the carbon used was in the form of molded balls one fourth inch in diameter. These were, of course, unable to offer any definite surface of contact. The other form was

the granular carbon used in telephones. But little was done with this because of the low pressures at which it had to be worked, for the instruments used were not accurate at such pressures.

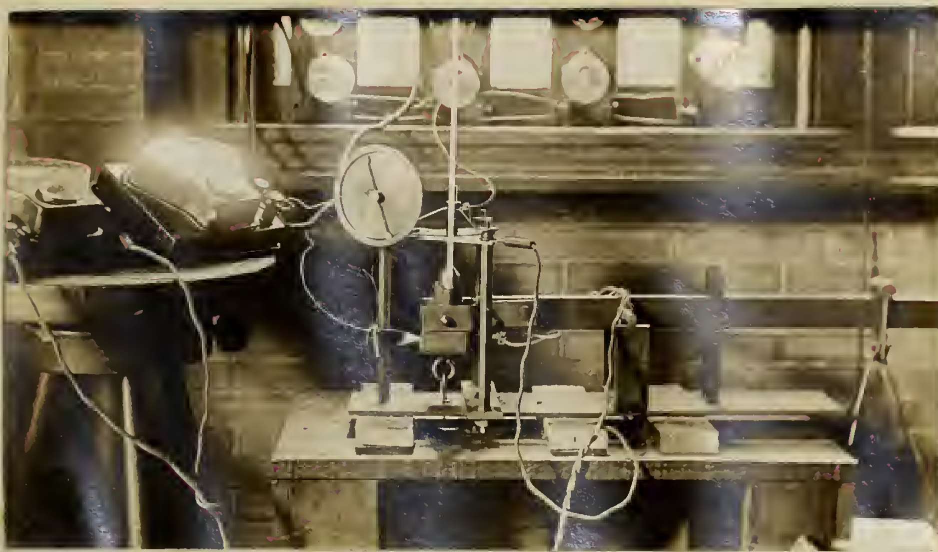


PLATE I

COMPRESSION MACHINE.

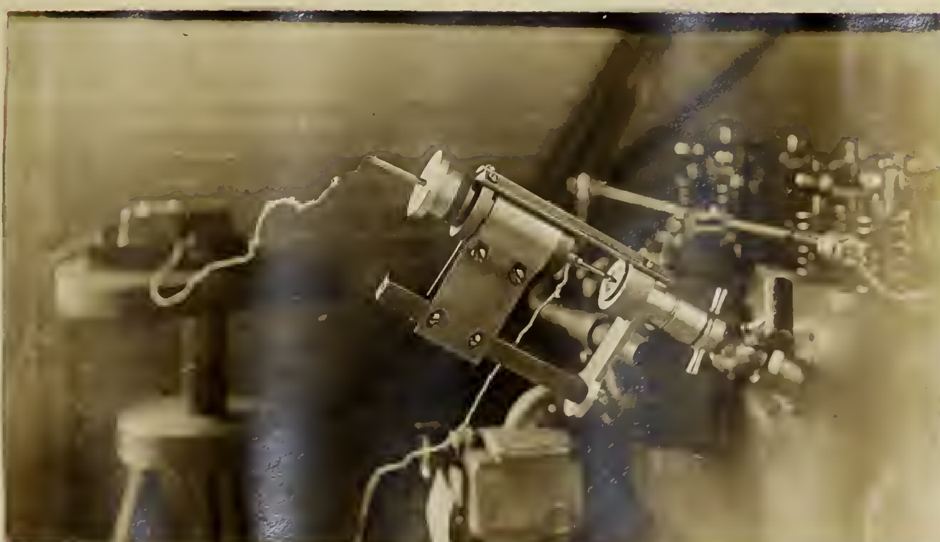


PLATE II

INDICATOR.

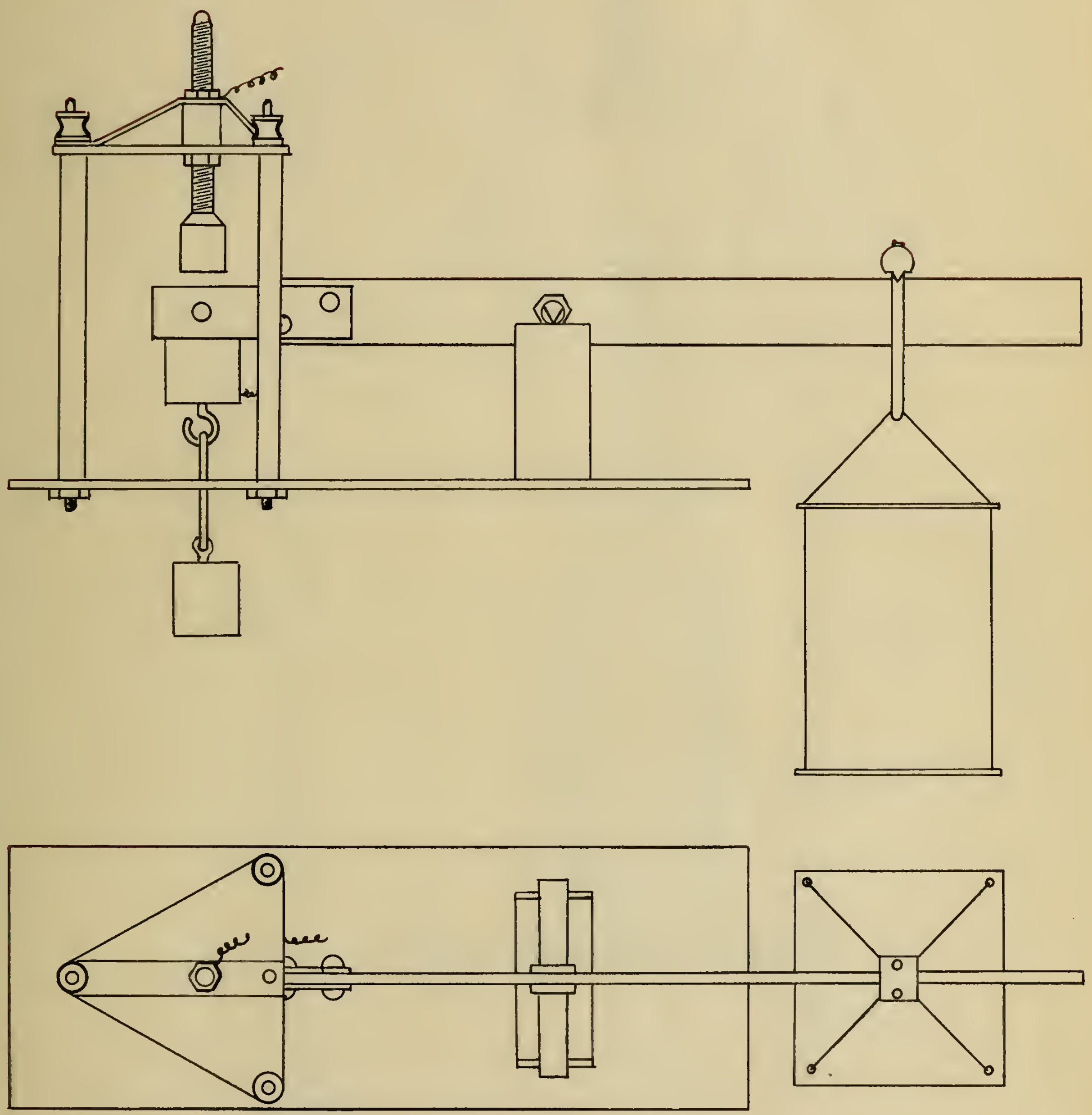


PLATE III

COMPRESSION MACHINE.

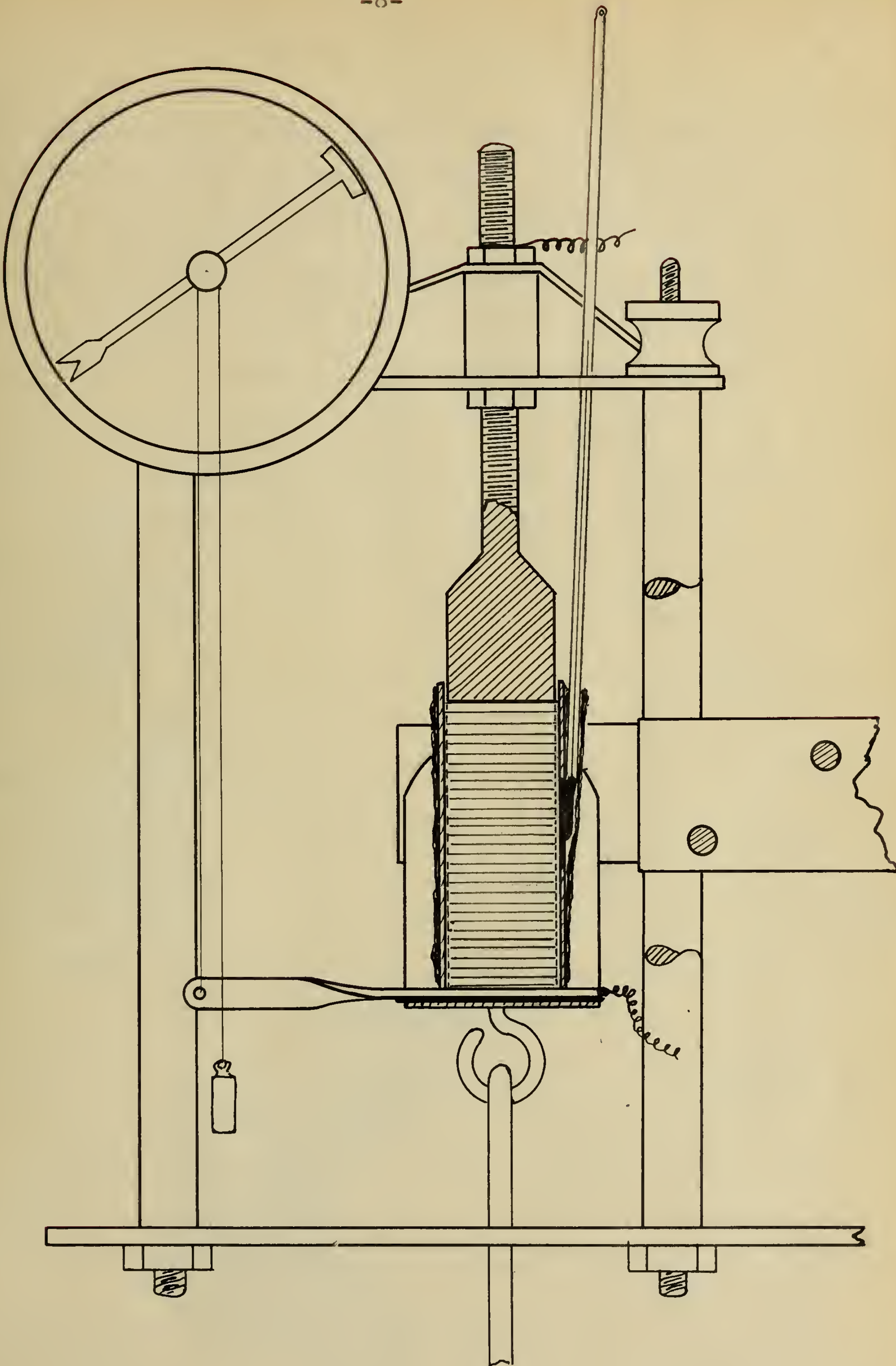


PLATE IV

COMPRESSION MACHINE DETAIL.

DESCRIPTION OF TESTS.

HIGH SPEED ENGINE INDICATOR-At first an investigation was made into the possibility of using some form of carbon to indicate the pressure in a high speed gas engine cylinder. For this purpose, the apparatus described on page four and shown on Plate two was constructed. The pressure from the engine cylinder was transmitted through the indicator piston to the carbon in the rubber tube. The carbon discs were connected in series with a storage battery and an oscillograph, as previously described. As the engine rotated, the pressure varied the resistance of the carbon in the tube. This then caused a variation of the current which was recorded on the oscillograph. As soon as it was found that any apparatus of this sort would necessitate complicated calibration tables, the project was given up and the investigation discontinued.

STATIC PRESSURE TESTS.-The testing machine described on Page 3 and shown on Page 6 was then constructed. Four sets of tests were run on the carbon discs to determine the variation of resistance with pressure. For these tests piles of eight, sixteen, twenty four and thirty two discs were used. The temperature during each test was kept constant so as to eliminate any errors due to changing temperature. The discs were placed in the machine as shown in Plate III and pressure applied by placing weights in the pan. The pressure was varied from one pound per square inch to about one hundred twenty pounds per square inch. An ammeter was placed in the circuit and a voltmeter across the pile. From these readings the resistance was calculated. Six readings were taken in each case, three being for ascending values of pressure and three for descending values. The average of the six values of resistance was

taken for the final result. Curves showing results are on Pages 12-18 .

A compression test was run on a pile of thirty two discs. A wire wound deflectometer reading in thousandths of an inch was fastened to the head of the machine and an arm extended from the base of the carbon pile. The wire was fastened to the end of this arm, as shown on Plate IV. The same range of pressures was applied to the discs as was used for the resistance tests. During this test, also, the temperature was kept constant. Readings of current, fall of potential and deformation were taken for each value of pressure. Curves showming relation of deformation to resistance and pressure are shown on Pages 22-24.

TEMPERATURE TESTS- Variations of resistance with temperature at constant pressure were also investigated. For this test a pile of thirty two carbon discs was used. They were placed in the machine as before and heated by the current which flowed through them. The temperature variation for each test was from about twenty five to one hundred degrees Centigrade. The resistance as in the other cases was measured by use of a voltmeter and an ammeter. The results of this test are shown by curves on Page 26.

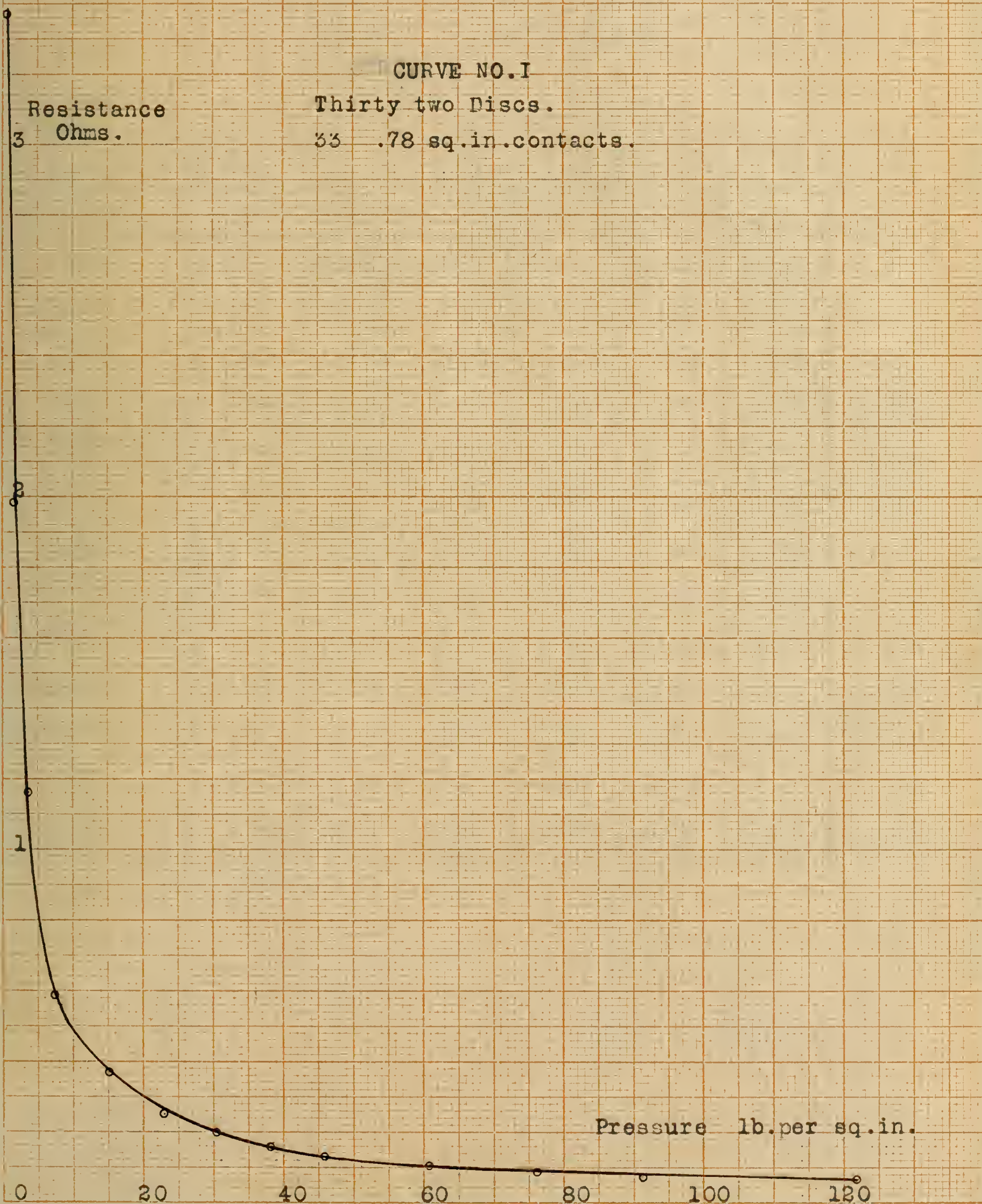
HIGH FREQUENCY TEST- The effect of high frequency currents was determined by sending the current from a static machine through a pile of thirty two discs. After the carbon had carried this high frequency current for several minutes a pressure resistance test was run. The resulting curve is shown on Page 30 and compared with the one previously taken and plotted on Page 12.

# DATA FOR CURVE 1.

## Variation of Resistance with Pressure.

## Thirty two Carbon Discs.

| Pressure | Resistance | | | | | | |
|---|---|---|---|---|---|---|---|
| Lb.per sq.in. | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Mean |
| .95 | 3.590 | 3.381 | 3.462 | 3.120 | 3.560 | 3.142 | 3.376 |
| 1.90 | 2.182 | 1.961 | 2.035 | 1.831 | 2.072 | 1.860 | 1.990 |
| 3.81 | 1.525 | 1.072 | 1.155- | 1.000 | 1.182 | 1.032 | 1.161 |
| 7.63 | .635 | .563 | .646 | .542 | .614 | .542- | .590 |
| 15.27 | .432 | .316 | .422 | .300 | .445 | .310 | .371 |
| 22.90 | .308 | .182 | .283 | .210 | .306 | .313 | .250 |
| 30.54 | .231 | .173 | .227 | .165 | .233 | .156 | .219 |
| 38.18 | .181 | .137 | .190 | .131 | .188 | .131 | .159 |
| 45.81 | .154 | .116 | .158 | .102 | .155 | .105 | .131 |
| 61.08 | .118 | .092 | .118 | .092 | .114 | .091 | .104 |
| 76.36 | .092 | .084 | .092 | .084 | .091 | .083 | .487 |
| 91.63 | .076 | .077 | .076 | .077 | .076 | .076 | .076 |
| 122.20 | .066 | .064 | .064 | .065 | .066 | .066 | .065 |


CURVE NO.I
Thirty two Discs.
33 .78 sq.in.contacts.
Resistance
Ohms.
3
2
1
Pressure lb.per sq.in.
0
20
40
60
80
100
120

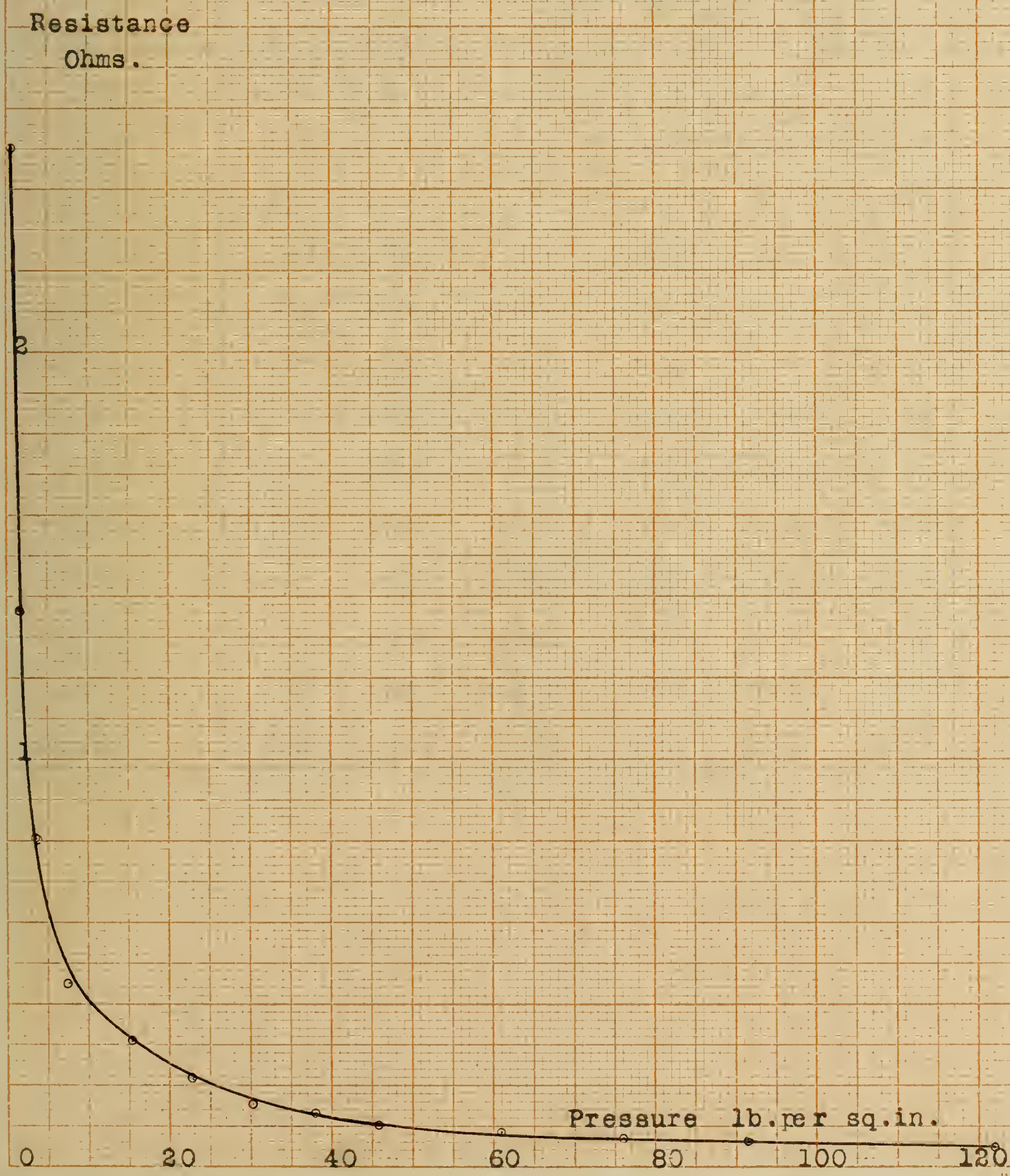
## DATA FOR CURVE 2.

Variation of Resistance with Pressure.

Twenty four Carbon Discs.

| Pressure | Resistance | | | | | | |
|---|---|---|---|---|---|---|---|
| Lb.per sq.in. | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Mean |
| .95 | 2.718 | 2.542 | 2.580 | 2.375 | 2.541 | 2.250 | 2.501 |
| 1.90 | 1.550 | 1.100 | 1.442 | 1.330 | 1.415 | 1.328 | 1.361 |
| 3.81 | .850 | .788 | .805 | .735 | .850 | .780 | .801 |
| 7.63 | .476 | .448 | .460 | .440 | .458 | .425 | .451 |
| 15.27 | .452 | .252 | .326 | .246 | .326 | .246 | .308 |
| 22.90 | .272 | .174 | .272 | .174 | .248 | .172 | .218 |
| 30.54 | .186 | .139 | .185 | .139 | .155 | .131 | .156 |
| 38.18 | .148 | .112 | .142 | .112 | .147 | .110 | .128 |
| 45.81 | .120 | .093 | .112 | .098 | .115 | .085 | .103 |
| 61.08 | .093 | .078 | .090 | .078 | .094 | .078 | .085 |
| 76.36 | .078 | .068 | .076 | .068 | .071 | .066 | .071 |
| 91.63 | .063 | .056 | .067 | .060 | .064 | .062 | .062 |
| 122.20 | .046 | .041 | .045 | .043 | .043 | .044 | .043 |

CURVE NO. 2.
Twenty four Discs.
25 .78 sq.in.contacts.



DATA FOR CURVE 3.

Variation of Resistance with Pressure.

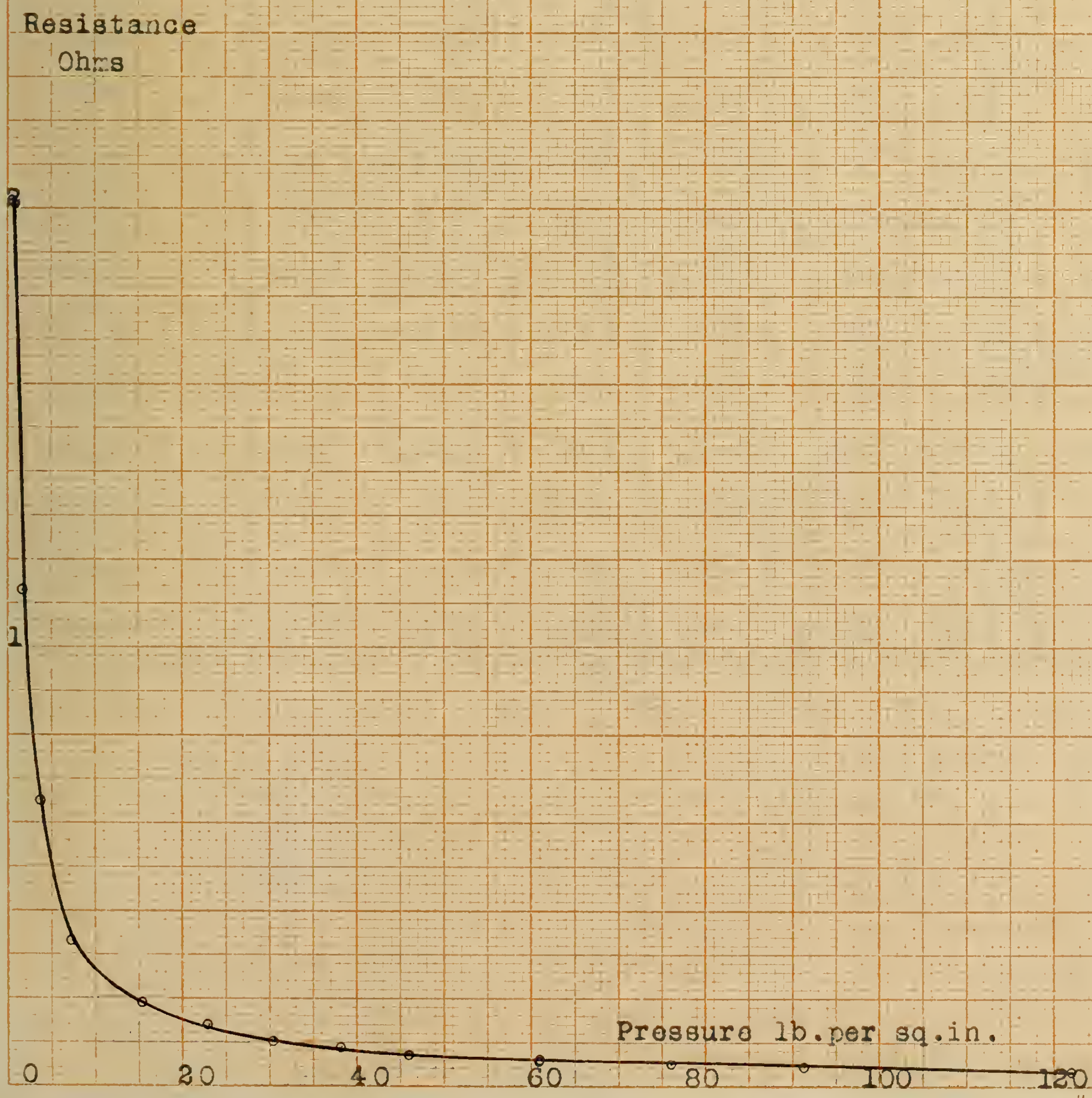
Sixteen Carbon Discs.

| Pressure | Resistance | | | | | | |
|---|---|---|---|---|---|---|---|
| Lb.per sq.in. | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Mean |
| .95 | 2.196 | 2.112 | 2.091 | 2.082 | 1.750 | 1.925 | 2.026 |
| 1.90 | 1.224 | 1.170 | 1.132 | 1.125 | 1.092 | 1.065 | 1.134 |
| 3.81 | .635 | .595 | .570 | .530 | .555 | .527 | .652 |
| 7.63 | .354 | .338 | .316 | .316 | .338 | .305 | .328 |
| 15.27 | .236 | .184 | .204 | .167 | .215 | .170 | .196 |
| 22.90 | .188 | .129 | .146 | .110 | .161 | .110 | .140 |
| 30.54 | .136 | .093 | .108 | .084 | .125 | .086 | .105 |
| 38.18 | .104 | .079 | .090 | .074 | .101 | .070 | .086 |
| 45.81 | .092 | .070 | .077 | .068 | .084 | .062 | .075 |
| 61.08 | .067 | .060 | .063 | .052 | .062 | .054 | .059 |
| 76.36 | .055 | .052 | .052 | .047 | .052 | .048 | .051 |
| 91.63 | .048 | .048 | .045 | .043 | .043 | .043 | .045 |
| 122.20 | .038 | .037 | .036 | .040 | .042 | .036 | .038 |

CURVE NO.3.

Sixteen Discs.

17 .78 sq.in.contacts.



DATA FOR CURVE 4.

Variation of Resistance with Pressure.

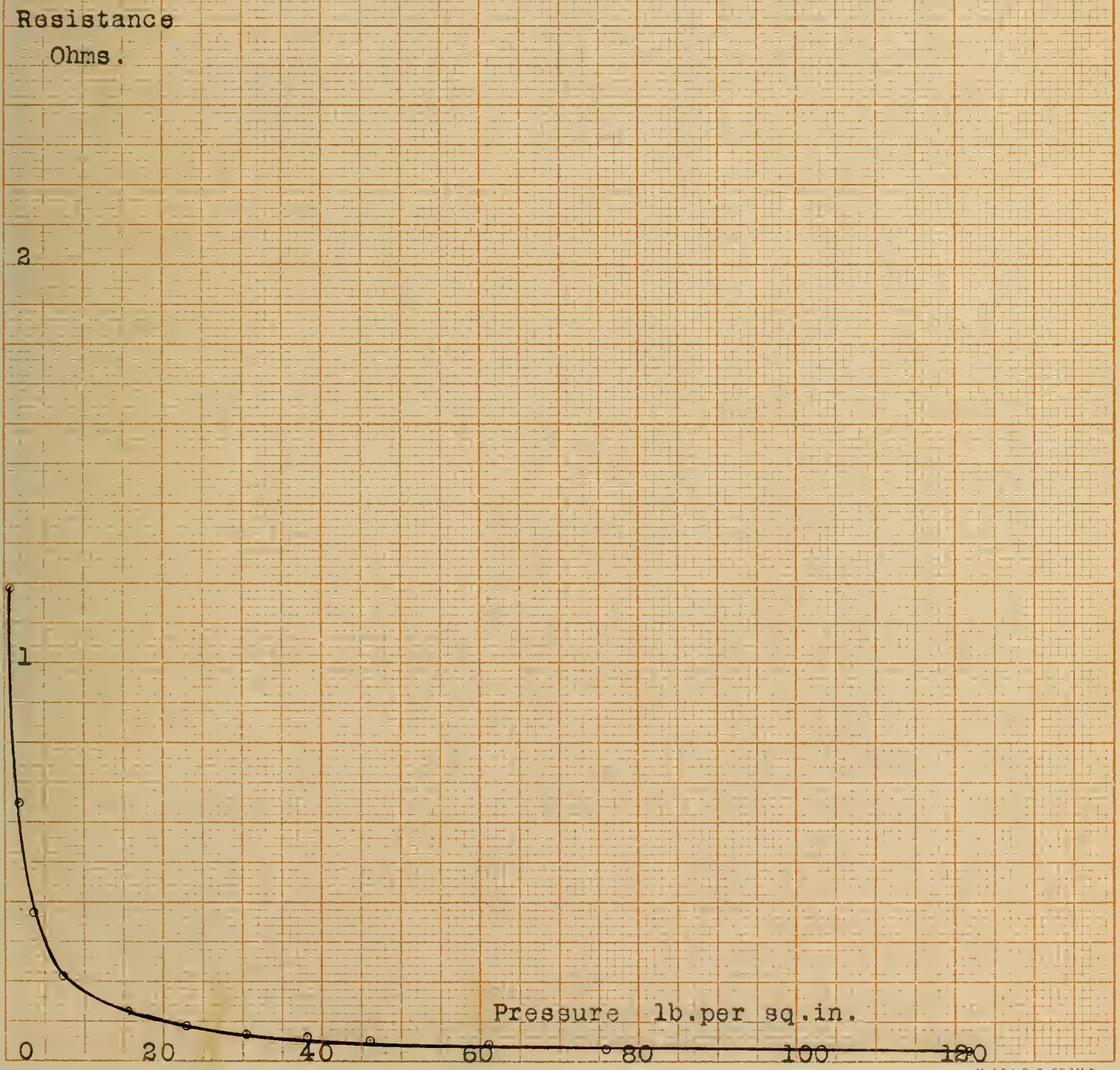
Eight Carbon Discs.

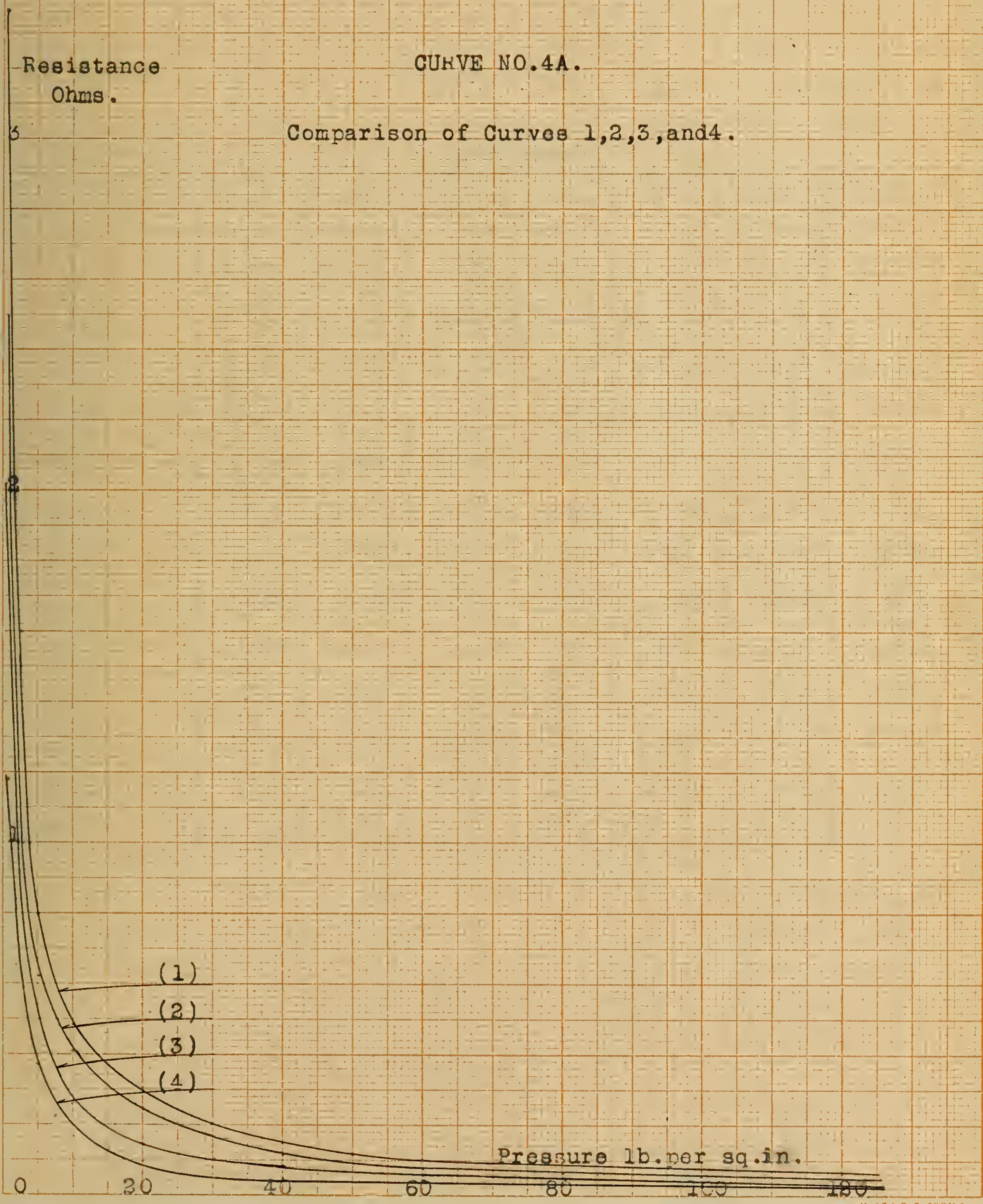
| Pressure | Resistance | | | | | | |
|---|---|---|---|---|---|---|---|
| Lb.per sq.in. | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Mean |
| .95 | 1.262 | 1.172 | 1.240 | 1.200 | 1.283 | 1.192 | 1.225 |
| 1.90 | .624 | .655 | .665 | .635 | .762 | .552 | .649 |
| 3.81 | .420 | .355 | .359 | .354 | .400 | .374 | .377 |
| 7.63 | .284 | .211 | .203 | .187 | .221 | .192 | .216 |
| 15.27 | .177 | .107 | .126 | .091 | .148 | .096 | .124 |
| 22.90 | .123 | .073 | .092 | .065 | .112 | .067 | .089 |
| 30.54 | .092 | .063 | .072 | .051 | .085 | .055 | .069 |
| 38.18 | .075 | .051 | .060 | .047 | .070 | .051 | .059 |
| 45.81 | .061 | .046 | .049 | .042 | .054 | .042 | .049 |
| 61.08 | .047 | .038 | .042 | .037 | .047 | .033 | .040 |
| 76.36 | .040 | .036 | .033 | .034 | .033 | .031 | .034 |
| 91.63 | .034 | .035 | .031 | .031 | .030 | .030 | .032 |
| 122.20 | .022 | .027 | .026 | .024 | .027 | .026 | .025 |

CURVE NO.4.

Eight Discs.

9 .78 sq.in.contacts.




Resistance
Ohms.
CURVE NO.4A.
Comparison of Curves 1,2,3,and4.
3
2
1
(1)
(2)
(3)
(4)
Pressure lb.per sq.in.
0
20
40
60
80
100
120

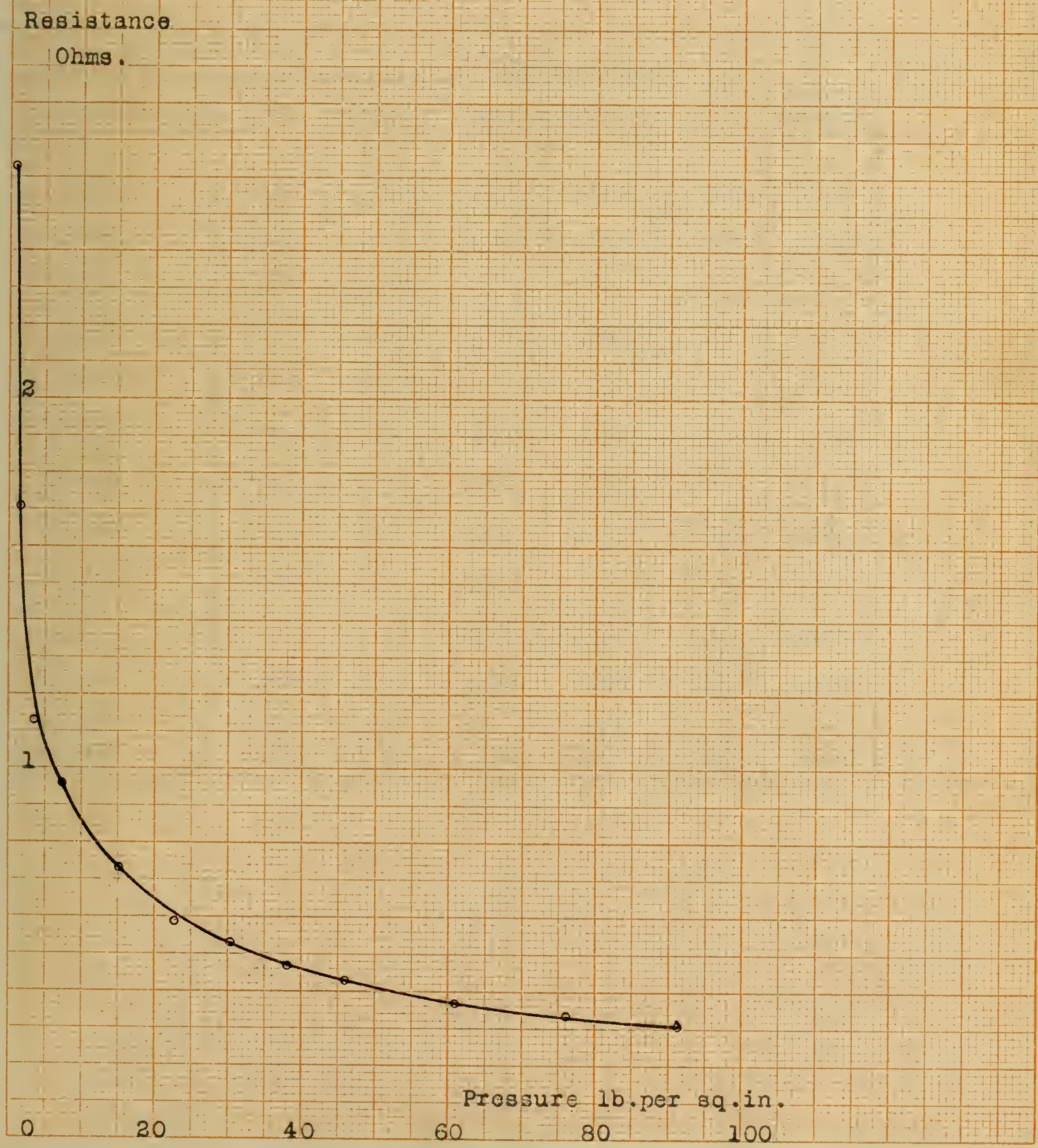
DATA FOR CURVE 5.

Variation of Resistance with Pressure.

Thirty Carbon Balls.

| Pressure | Resistance | | | | | | |
|---|---|---|---|---|---|---|---|
| Lb.per sq.in. | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Mean |
| .95 | 3.121 | 1.782 | 3.810 | 1.666 | 3.422 | 1.968 | 2.628 |
| 1.90 | 1.932 | 1.322 | 2.228 | 1.224 | 2.120 | 1.436 | 1.710 |
| 3.81 | 1.510 | .950 | 1.222 | .948 | 1.184 | .956 | 1.128 |
| 7.63 | 1.110 | .875 | 1.020 | .778 | .982 | .781 | .957 |
| 15.27 | .888 | .637 | .831 | .592 | .852 | .620 | .733 |
| 22.90 | .685 | .565 | .630 | .496 | .642 | .541 | ..593 |
| 30.54 | .634 | .500 | .517 | .443 | .602 | .488 | .530 |
| 38.18 | .550 | .444 | .464 | .418 | .528 | .432 | .472 |
| 45.81 | .493 | .404 | .434 | .388 | .467 | .412 | .433 |
| 61.08 | .390 | .372 | .367 | .346 | .373 | .356 | .367 |
| 76.36 | .362 | .346 | .335 | .316 | .346 | .324 | .338 |
| 91.63 | .335 | .332 | .305 | .305 | .310 | .308 | .316 |

CURVE NO.5.



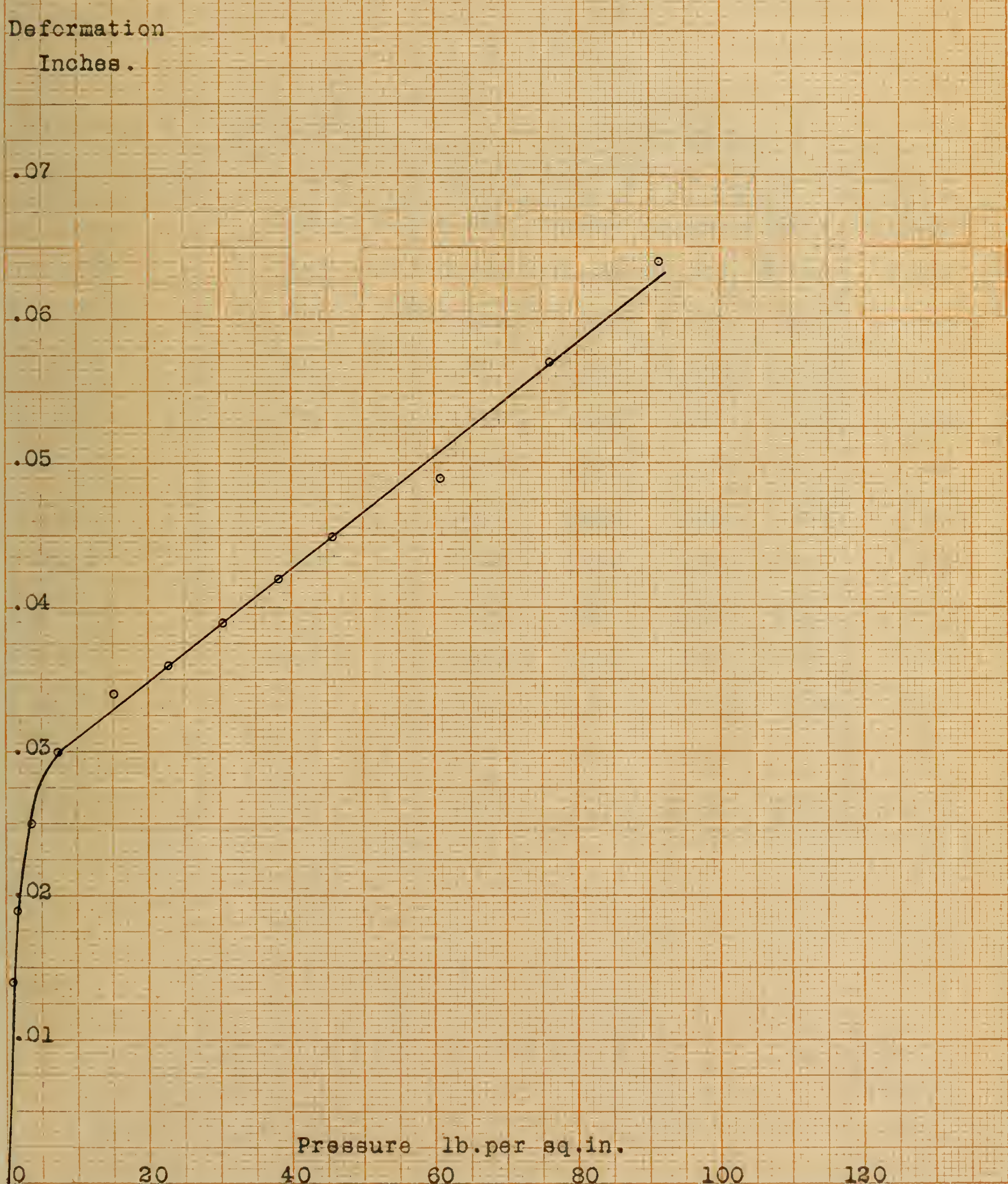
DATA FOR CURVE 6.

Deformation with Pressure.

Thirty two Carbon Discs.

| Pressure | Deformation | | | | | |
|---|---|---|---|---|---|---|
| Lb.per sq.in. | Test 1 | Test 2 | Test 3 | Test 4 | Mean | Cor-rected |
| .00 | .000 | -.008 | -.008 | -.005 | -.005 | -.000 |
| .95 | .015 | .007 | .005 | -.009 | .009 | ..014 |
| 1.90 | .018 | .014 | .012 | .014 | .014 | .019 |
| 3.81 | .023 | .020 | .018 | .021 | ..020 | .025 |
| 7.63 | .026 | .026 | .024 | .027 | .025 | .030 |
| 15.27 | .026 | .032 | .029 | .032 | .029 | .034 |
| 22.90 | .028 | .034 | .031 | .034 | .031 | .036 |
| 30.54 | .029 | .036 | .033 | .038 | .034 | .039 |
| 38.18 | .031 | .040 | .035 | .041 | .037 | .042 |
| 45.81 | .035 | .042 | ..038 | .044 | .040 | .045 |
| 61.08 | .042 | .049 | .045 | .050 | .044 | .049 |
| 76.36 | .048 | .054 | .051 | .055 | .052 | .057 |
| 91.63 | .059 | .059 | .060 | .060 | .059 | .064 |

CURVE NO.6.

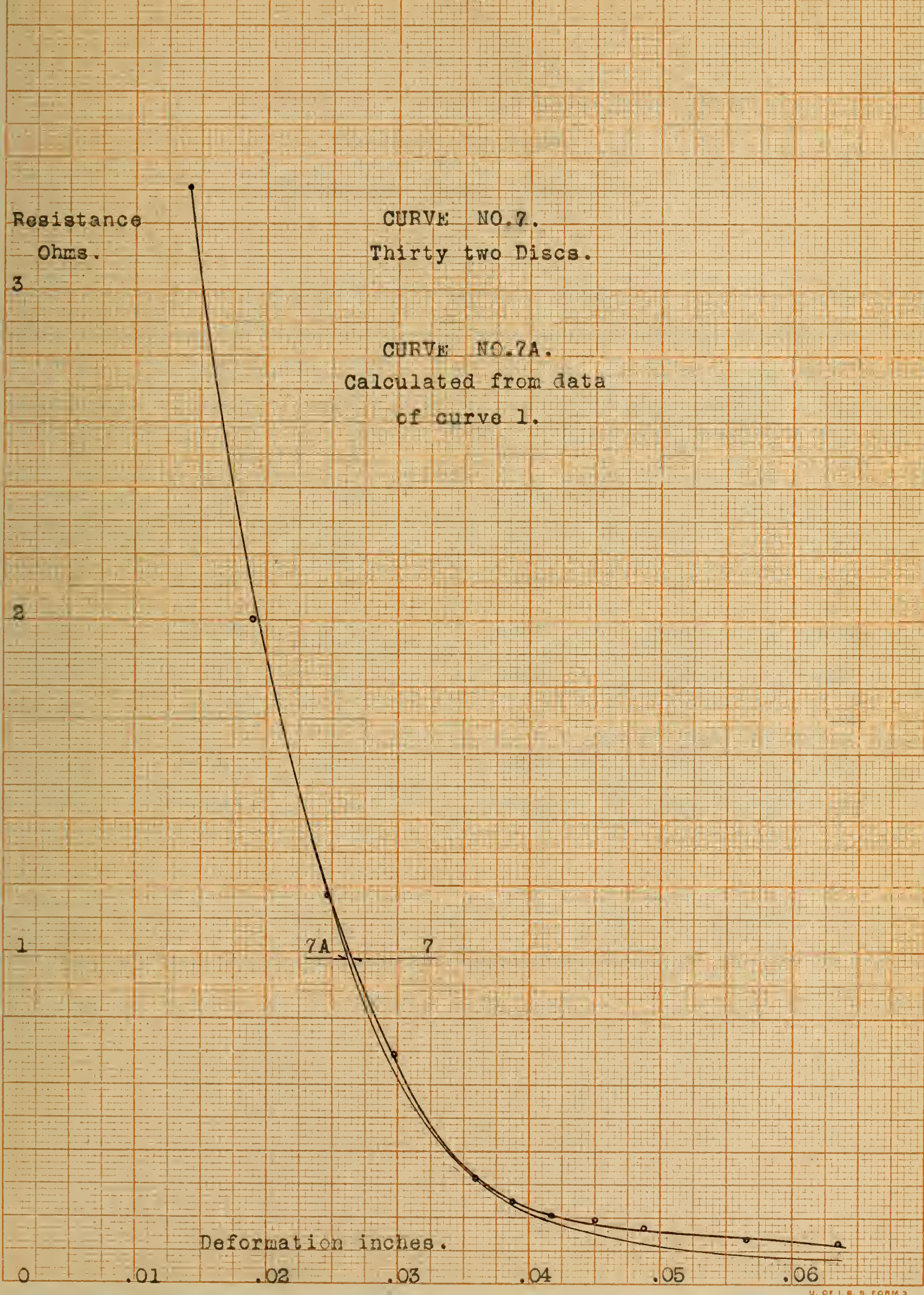

Deformation
Inches.
.07
.06
.05
.04
.03
.02
.01
Pressure lb.per sq.in.
0
20
40
60
80
100
120

DATA FOR CURVE 7.

Variation of Resistance with Deformation.

Thirty two Carbon Discs.

| Pressure | Deformation | Resistance | | | | |
|---|---|---|---|---|---|---|
| Lb.per sq.in. | Inches | Test 1 | Test 2 | Test 3 | Test 4 | Mean |
| .00 | .000 | 18.200 | 24.420 | 22.180 | 20.642 | 21.380 |
| .95 | .014 | 3.451 | 3.262 | 3.338 | 3.200 | 3.312 |
| 1.90 | .019 | 2.252 | 1.831 | 2.130 | 1.842 | 2.013 |
| 3.81 | .025 | 1.375 | 1.042 | 1.208 | 1.034 | 1.164 |
| 7.63 | .030 | .826 | .650 | .618 | .635 | .682 |
| 15.27 | .034 | ..472 | .376 | .412 | .354 | .403 |
| 22.90 | .036 | .378 | .274 | .331 | .269 | .313 |
| 30.54 | .039 | .298 | .224 | .270 | .234 | .256 |
| 38.18 | .042 | .256 | .193 | .235 | .191 | .218 |
| 45.81 | .045 | .228 | .188 | .212 | .178 | .201 |
| 61.08 | .049 | .181 | .153 | .172 | .151 | .164 |
| 76.36 | .057 | .151 | .138 | .149 | .139 | .144 |
| 91.63 | .064 | .133 | .129 | .133 | .130 | .131 |




U. OF I. S. S. FORM 3

DATA FOR CURVE 8.

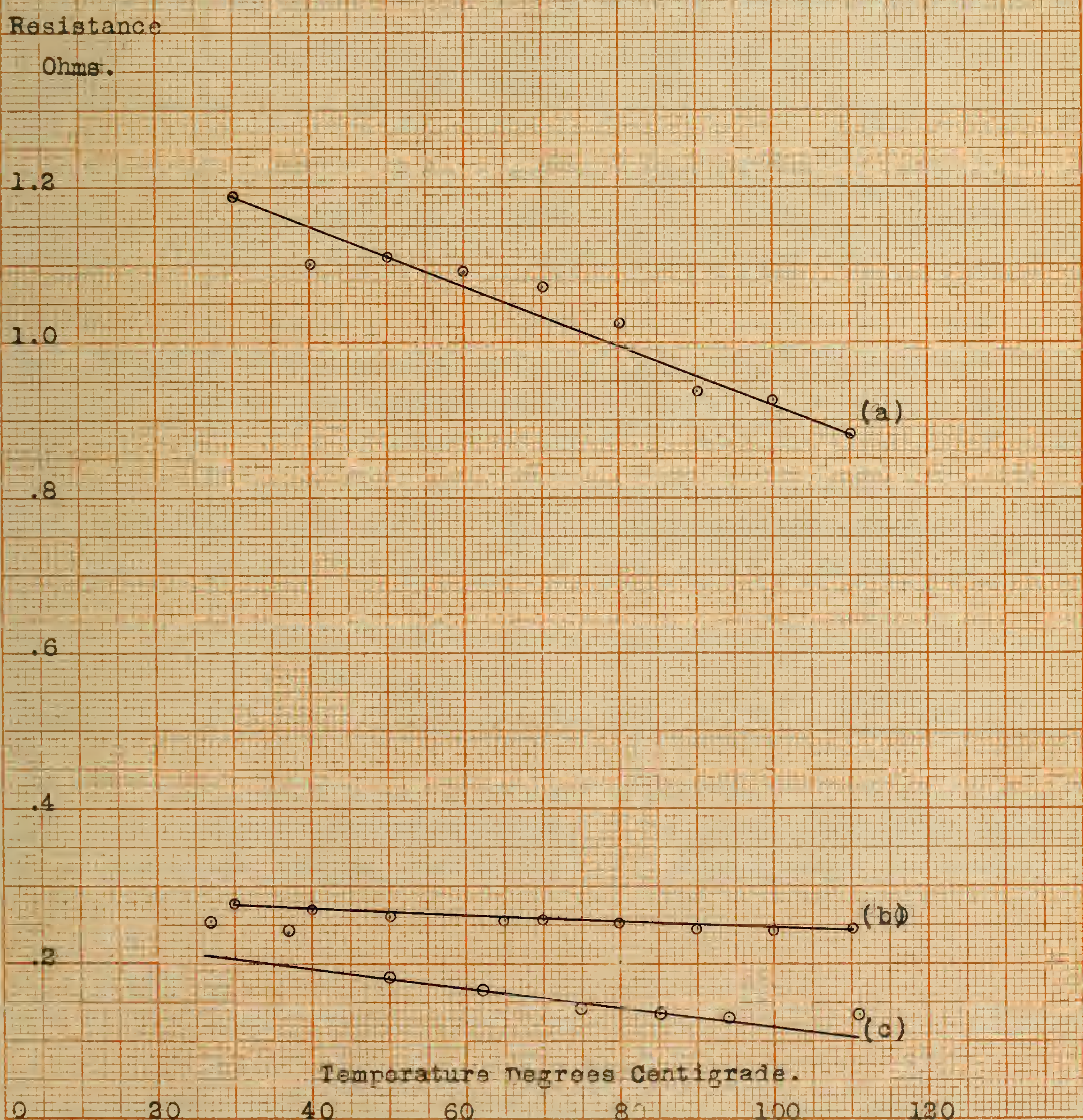
Variation of Resistance with Temperature.

Constant Pressure.

Thirty two Carbon Discs.

| (a) 3.81 lb.per sq.in. | | (b)15.27 lb.per sq.in. | | (c)38.18 lb.per sq.in. | |
|---|---|---|---|---|---|
| Temp. Deg.Cent. | Resist. Ohms. | Temp. Deg. Cent. | Resist. Ohms. | Temp. Deg. Cent. | Resist. Ohms. |
| 30 | 1.190 | 30 | .279 | 27 | .256 |
| 40 | 1.102 | 40 | .269 | 37 | .242 |
| 50 | 1.110 | 50 | .262 | 50 | .182 |
| 60 | 1.091 | 65 | .257 | 62 | .167 |
| 70 | 1.072 | 70 | .257 | 75 | .142 |
| 80 | 1.024 | 80 | .252 | 85 | .137 |
| 90 | .937 | 90 | .248 | 94 | .132 |
| 100 | .927 | 100 | .245 | 100 | .130 |
| 110 | .880 | 110 | .242 | 110 | .137 |

CURVE NO. 8.


Resistance
Ohms.
1.2
1.0
.8
.6
.4
.2
(a)
(b)
(c)
Temperature Degrees Centigrade.
0
20
40
60
80
100
120

DATA FOR CURVE 9.

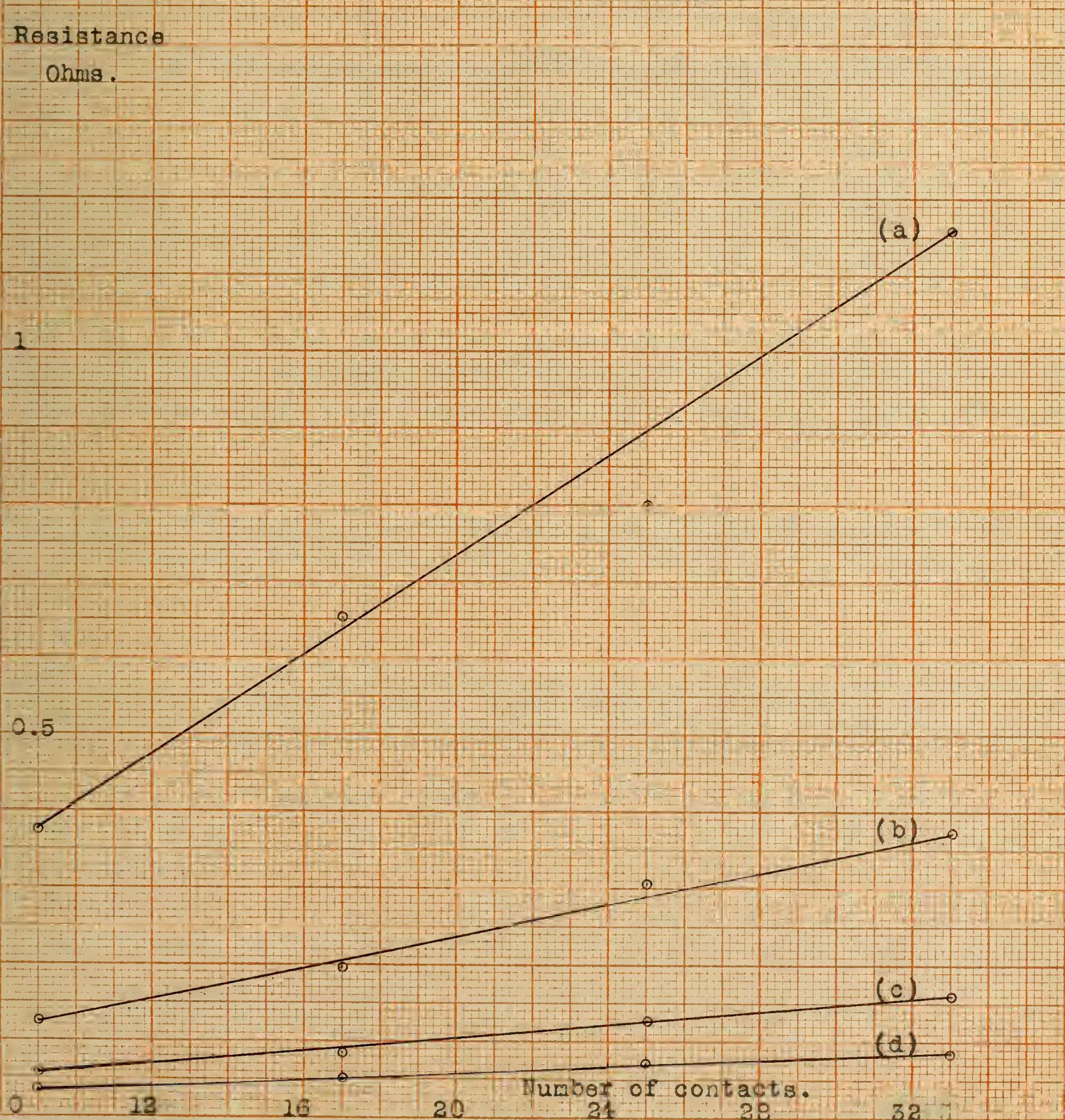
Variation of Resistance

with Number of Contacts.

Constant Pressure.

| | Pressure in lb. per sq. in. | | | |
|---|---|---|---|---|
| Number of Contacts. | (a) 3.81 | (b) 15.27 | (c) 38.18 | (d) 76.36 |
| | Resistance in Ohms. | | | |
| 9 | .377 | .124 | .059 | .034 |
| 17 | .652 | .196 | .086 | .051 |
| 25 | .801 | .308 | .128 | .071 |
| 33 | 1.161 | .371 | .159 | .087 |

CURVE NO. 9.



Resistance
Ohms.
1
0.5
(a)
(b)
(c)
(d)
Number of contacts.
0
12
16
20
24
28
32

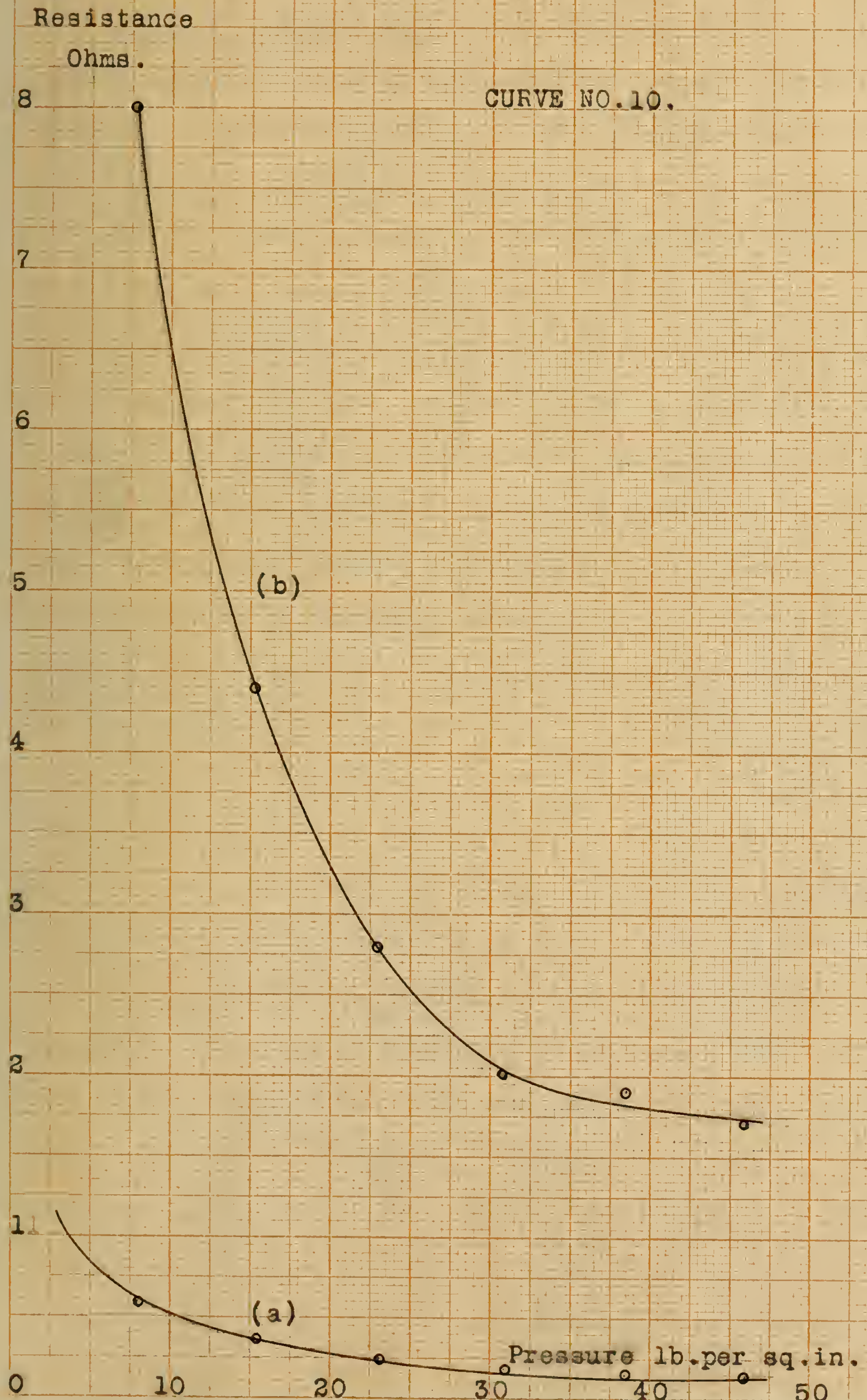
DATA FOR CURVE 10.

Effect of High Frequency Current

on Resistance.

Thirty two Carbon Discs.

| Pressure | Resistance | |
|---|---|---|
| Lb.per sq.in. | Normal | After passage of Current |
| 7.63 | .590 | 8.0 |
| 15.27 | .371 | 4.4 |
| 22.90 | .250 | 2.8 |
| 30.54 | .199 | 2.0 |
| 38.18 | .159 | 1.9 |
| 45.81 | .151 | 1.71 |


Resistance
Ohms.
CURVE NO.10.
8
7
6
5
4
3
2
1
0
(b)
(a)
Pressure lb.per sq.in.
10
20
30
40
50

## DISCUSSION OF RESULTS.

STATIC PRESSURE TEST - The results of the investigation of carbon in the form of discs are shown in the preceding curves and tables. In the tests there were found two factors which effected the contact resistance. One is that of form, the other is the structure of the material. At low pressures both acted. Theoretically, the carbon discs were flat with parallel sides, but owing to their thinness it was impossible to keep them from warping and changing their shape. Before enough pressure had been applied to flatten all the discs, the contact surface was very much reduced on account of this warping. At low pressures the contact resistance was very high and changed rapidly as the pressure was increased. This is shown by the rapid descent of the curves for the lower pressures. As soon as all surfaces had become parallel, this rapid change stopped and the effect of the structural form became most prominent. As shown by the part of the curve for higher pressures the effect of this is very much less than the former. As a result of these two factors, the curves showing the relation of resistance to pressure assume the form of equilateral hyperbolas, the equation of which is $PR = K$, $P$ being in pounds per square inch on the contacts and $R$ the resistance of the pile in ohms. Between fifteen and seventy pounds the equation $PR = 6$ closely approximates the curve for thirty two discs. Over this same range $PR = 4.77$ for a pile of twenty four discs. When fewer than this number of discs were used the equation ceased to hold for more than a small fraction of the curve. It would seem from this that a larger number

of discs might give a curve that would fit the equation over a greater range of pressures. For low pressures the arrangement of the pile had a noticeable effect on the contact resistance. This is due to the shape of the discs, for by placing them differently the contact surface could be changed and so change the resistance for any given pressure. This effect was eliminated when the pressure became sufficiently great to bring all the surface into contact.

With the carbon balls it was difficult to get any definite surface in contact. This is shown by the variation in the different sets of data taken. The curve of average values of resistance is shown on Page 20.

The results of the compression test as plotted on Page 22 show that the same factors are effective in causing the deformation as in changing the resistance. As pressure is applied, the discs are brought together very quickly until they are flat against each other. At a pressure of about ten pounds per square inch, the deformation decreases and becomes more nearly that of solid carbon. The relation between resistance and deformation is of the nature of the relation of resistance to pressure. The curve between resistance and deformation is shown on Page 24.

TEMPERATURE TESTS- The results of the tests for temperature-resistance relations are shown on Page 26. The curves show that carbon has a negative coefficient of resistance. The variation of resistance with temperature at low pressures was greater than at high pressures.

HIGH FREQUENCY TEST- As shown by the curves on Page 30, the effect of high frequency currents is to raise the resistance of carbon.

After carrying such a current for a short time the resistance was found to be increased about fourteen hundred percent. The relation of resistance to frequency was not determined on account of the impossiblity of determining the frequency in these cases. The general effect, however, was quite evident. The element of time also entered into this test as the resistance changed with the length of time during which the carbon carried the high frequency current.

DISCUSSION OF ERRORS- In an investigation of this sort, errors are naturally introduced. Care was taken, however, to obtain enough data so that by using a mean value of a large set of readings, some errors might be eliminated. Only a small number of carbon discs were available, so these had to be used throughout the entire investigation . Several of them became slightly pitted on account of arcing when the circuit was not opened before the pressure was removed from them. One of the results of this is shown in the discrepancy between curves 7 and 7A. The data for curve 7A was taken about a week before that of curve 7 and during that time the discs were removed from the machine and also subjected to various pressures and temperatures. It must also be remembered that the equations evolved apply only to the specific pile of carbon discs from which the data was taken. The resistance of the pile would, of course, increase with the number of contacts and decrease as the cross - section increases, but since no discs of larger area were available, it was impossible to formulate equations to fit all cases. It could be assumed, however, that the change due to cross-section would be the same as for a solid conductor.

## CONCLUSION.

As previously stated, the object of this investigation was to determine the relation existing between contact resistance and the pressure bearing on the contact. As shown by the foregoing data and curves, this relation is given by the equation $PR = K$ when a large number of contacts are placed in series as in the pile of thirty two carbon discs used in the experiment. The use of this contact resistance phenomenon does not, however, depend on the equation of the curve. For any certain pile of discs, suitable calibration curves such as those on preceding pages can be constructed and used to calculate the pressure indicated by the resistance of the pile. The use for any instrument employing the contact resistance phenomenon would be where conditions prevented the placing of indicating or recording instruments at the point where pressures were to be measured. Such conditions might exist in measuring the pressure against dams or walls under water or wind pressures at high altitudes.

It would, however, be highly impractical to use anything of this sort where the pressure is rapidly changing as in a high speed gas engine cylinder. The indication would have to be taken with an oscillograph and then corrected by use of calibration curves. For this reason an engine indicator using the carbon phenomenon would never be a commercial success.